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HIGH DENSITY JET FUEL AVAILABILITY STUDY

PHASE I -- Refining Industry Survey

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Survey of ten refining companies to explore production schemes, raw materials processing costs and potential quantities of high-density jet fuel is summarized. Estimated regional and national production capabilities are presented along with estimated manufacturing costs. Access to potential feedstock samples is also discussed. Refining issues and consideration for further study are presented.

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SUMMARY

Results from the refinery survey portion (Phase I) of this study indicate that production of high-density jet fuel (HDJF) will pose no insurmountable problems for the U.S. refining industry.

The industry's maximum capability to produce high-density fuels which can be used in present-day Air Force jet engines (near-term HDJF) is estimated at 324,000 barrels per calendar day, well above current JP-4 production. The maximum capability for production of even higher-density fuels for future engine designs (far-term HDJF) is much greater, totaling an estimated 1,437,000 barrels per calender day -- about seven times the current production volume for JP-4.

Regionally, the preponderance of near-term HDJF production capability is in refineries on the West Coast and Gulf Coast, although significant volumes could be produced in refineries located in the Midcontinent region. Far-term HDJF production capability is also concentrated on the West and Gulf Coasts, although significant capability for such production exists in all regions of the U.S.

Refining industry costs for producing HDJF depends heavily on the price of crude oil. This study estimates that near-term HDJF costs would be $16.05 per barrel (38 cents/gallon) using $15/barrel crude oil. For crude costs of $20/barrel, the cost of near-term HDJF is estimated at $21.31 per barrel (51 cents/gallon). These cost include investments for addition of product storage and transfer facilities, but no investment in processing would be required.

Costs for producing far-term HDJF are estimated at $20.46 per barrel using $15/barrel crude oil and at $25.69 per barrel using $20/barrel crude oil. This equates to 49 cents and 61 cents/gallon, respectively. Production of this higher density fuel incurs additional processing costs of approximately $4.50 per barrel to meet specifications which limit aromatics content.

More than 70 different feedstock samples were offered for analysis by the 10 refining companies surveyed. These range from straight-run kerosenes to a variety of cracked distillates -- including a kerosene from Canadian Tar Sands synthetic crude processing. Samples were offered from sources in every major U.S. petroleum refining center.

PREFACE

This interim report has been furnished by Bonner & Moore Associates, Inc. of Houston, Texas, to the Propulsion Laboratory of the Aeronautical Systems Division/PMRSA, Wright-Patterson AFB, Ohio 45433-6503 under Contract No. 33615-85-C-2529. The work reported here was performed by Bonner & Moore Associates, Inc. and its sole subcontractor, Southwest Research Institute of San Antonio, Texas. Conclusions and opinions expressed are those of the authors and are not necessarily those of the U.S. Air Force, its members or employees, nor those of refining companies who were interviewed as part of the work effort of this phase of the project. Any mention of company or product names is not to be considered as an endorsement by the authors, or the U.S. Air Force.

Information supplied by participating oil companies and used in this study has been employed without identifying sources of specific data. This anonymity was guaranteed by the survey team to encourage participating companies to provide as much detail as possible. Other information used in this study has been obtained from public sources or is common knowledge. To further protect participants, no distinction is made between supplied and public information. All results are, therefore, the responsibility of the authors and cannot be related to any one or several sources.

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SECTION 1

INTRODUCTION

This interim report summarizes the study activities and results for Phase I of a multi-phase project to assess the potential availability and cost of high-density jet fuel (HDJF) in the U.S. This project is funded under Contract No. 33615-85-C-2529 between the U.S. Air Force Propulsion Laboratory at Wright-Patterson and Bonner & Moore Associates, Inc., (Contractor). HDJFs are of interest because they provide higher volumetric heats of combustion than current naphtha or kerosene military jet fuels and, therefore, offer increased operating ranges for volume-limited military aircraft.

In Phase I, we surveyed ten refineries and arranged to secure offerings of feedstock samples suitable for Phase II purposes. Information gathered during the survey was also used in preparing estimates of the quantity and quality of crude oils and other refinery streams which could serve as feedstocks for HDJF production. Additionally, cost estimates for manufacturing high-density jet fuels were to be prepared using survey information.

We guaranteed each participating company that information obtained during survey interviews would not be identified by source and that no proprietary information would be published without written permission. Further, names of companies offering feedstock samples will not be associated with descriptions of those streams which they have offered as feedstock samples.

Beyond this introduction, this report discusses survey participants in Section 2, a summary of results in Section 3, volume and costs projections for HDJF in Section 4, and problems requiring further analysis in Section 5. Appendices provide additional information in support of the material contained in the body of this report.

SECTION 2

SELECTION OF SURVEY PARTICIPANTS

To provide a representative sampling of U.S. refining situations, the survey conducted under Phase I of this study was designed to meet certain criteria, some of which were stipulated in the Contract Statement of Work (SOW) and some of which were imposed by the Contractor to make the sampling representative and effective in terms of processing information.

2.1 SELECTION CRITERIA

Sampling required by the SOW included a minimum of ten refineries with sizes ranging from "mid-sized to large." Further, these refineries were to be situated in the West Coast, East Coast, Gulf Coast, and Mid-Continent regions of the U.S.

Because the information sought by the survey typically resides among refinery planning, engineering, supply and marketing organizations and is not within the responsibility of refinery operating staff, the Contractor imposed the criterion of meeting with corporate or refining headquarters people when these were different from refinery operations management. Initial contacts were, therefore, with corporate staff and most interviews were conducted at headquarters locations. Two refineries were visited during the course of the survey. Although left to each company's discretion, it was suggested that each interview include representatives from appropriate product marketing organizations, from research and engineering staffs, and from refinery planning and operating groups.

Where possible, the Contractor chose refining companies that also owned crude production. It was felt that these integrated companies would be able to supply crude quality and production figures not normally available to non-integrated refiners. The final sample, however, excludes several significant crude oil producers. When possible, companies known to have process research and development functions were preferentially selected. Again, several prominent licensors of technology were not in the set surveyed.

2.2 SELECTED COMPANIES

In all, 14 refining companies were contacted. Four of the first ten contacted declined to participate. Their reasons for nonparticipation were either that they were unable to see a favorable business potential for producing HDJFs or that they had already contributed as much data as seemed reasonable toward exploration of this subject.

Table 2-1 lists each participating company and its refineries. Thirty-seven operating refineries are shown. Reported throughput capacities and refinery process types are taken from the Oil & Gas Journal publication (24 March 1986, pp. 100-115).

TABLE 2-1

PARTICIPATING COMPANIES AND REFINERIES

COMPANY	LOCATION	REFINERY CAPACITY	TYPE
AMOCO	Casper, Wyo.	40,000	Cracking + Lubes
	Mandan, N. Dak.	58,000	Cracking
	Salt Lake City, Utah	40,000	Complex
	Savannah, Ga.	28,000	Topping + Asphalt
	Texas City, Tex.	400,000	Complex
	Whiting, Ind.	350,000	Complex + Lubes
	Yorktown, Va.	51,000	Cracking
		967,000	
ARCO	Carson, Calif.	211,000	Cracking
	Ferndale, Wash.	156,000	Hydrocracking
	North Slope, Alaska	34,000	Topping
	Pasadena, Tex.	278,000	Complex + Lubes
		679,000	
ASHLAND	Canton, Ohio	66,000	Cracking + Asphalt
	Catlettsburg, Ky.	213,400	Complex + Lubes
	St. Paul Park, Minn.	67,000	Cracking + Asphalt
		346,400	
DIAMOND SHAMROCK	Sunray, Tex.	85,000	Complex
	Three Rivers, Tex.	45,000	Cracking + Lubes
		130,000	
EDGINGTON	Long Beach, Calif.	41,600	Topping + Asphalt
HAWAIIAN INDEPENDENT	Ewa Beach, Hawaii	61,500	Hydroskimming
PARAMOUNT	Paramount, Calif.	46,500	Hydroskimming + Asphalt
SHELL OIL	Anacortes, Wash.	72,000	Cracking
	Deer Park, Tex.	228,500	Complex + Lubes
	Martinez, Calif.	113,500	Complex + Lubes
	Norco, La.	218,000	Cracking
	Odessa, Tex.	28,600	Complex
	Wilmington, Calif.	111,000	Cracking
	Wood River, Ill.	264,000	Complex + Lubes
		1,035,600	
SUN REFINING	Marcus Hook, Pa.	155,000	Complex + Lubes
	Toledo, Ohio	118,000	Complex
	Tulsa, Okla.	85,000	Complex + Lubes
		318,000	
TEXACO	Anacortes, Wash.	78,000	Cracking
	Bakersfield, Calif.	38,000	Hydroskimming
	Convent, La.	225,000	Cracking
	Delaware City, Del.	140,000	Complex
	El Dorado, Kans.	80,000	Complex
	El Paso, Tex.	17,000	Complex
	Port Arthur, Tex.	250,000	Cracking/Asphalt/Lubes
	Wilmington, Calif.	75,000	Cracking
		903,000	

TOTAL Sample: 4,528,200 BPCD

Refinery types indicated in Table 2-1 show that most refineries are equipped with cat cracking. Three are shown as topping refineries, meaning that there is no downstream processing after the crude distillation step. Three are hydroskimming refineries, meaning that downstream processing includes catalytic reforming and usually naphtha and distillate hydrotreating. Sixteen refineries are listed as cracking type, meaning that downstream processing includes (in addition to cat reforming) catalytic cracking, sometimes hydrocracking and, in one case, only hydrocracking. If aromatics manufacture is also indicated, the type is shown as complex. As a further description of process configuration, asphalt and lube production is also shown where applicable.

Total capacity in operation for the companies surveyed, amounts to approximately 4,528,000 BPCD. This represents 30 percent of the total U.S. refining capacity. Details of major process configurations are presented in Tables 2-2 through 2-6 which present refineries in each PAD District to show geographical representation of the refineries covered in survey work. PAD Districts, depicting the regions used in this analysis, are shown in Figure 1. Table 2-7 presents the summary of PAD District configurations.

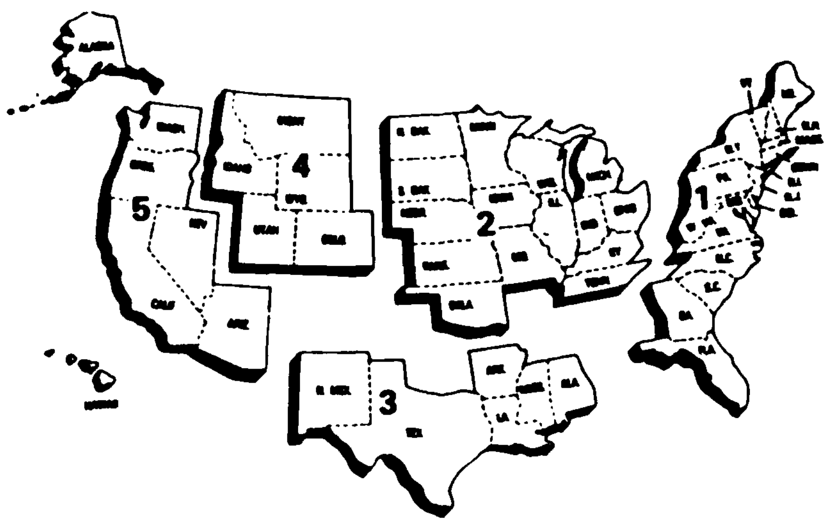

Figure 1. Petroleum Administration for Defense (PAD) Districts

TABLE 2-2

PAD DISTRICT 1 CONFIGURATIONS
(MBPCD)

COMPANY: CITY: STATE:	AMOCO SAVANNAH GA	AMOCO YORKTOWN VA	SUN MARCUS HOOK PA	TEXACO DELAWARE CITY DE	TOTAL IN PADD 1
CRUDE DISTILLATION	28.0	51.0	155.0	140.0	374.0
VACUUM DISTILLATION		26.7	42.3	87.4	156.4
DELAYED COKER		12.7			12.7
COKE DRUM		0.8		2.0	2.8
FLUID COKER				41.4	41.4
VISBREAKER					
THERMAL CRACKER					
FLUID CAT CRACKER		27.7	80.8	70.5	179.0
HVY. OIL CRACKER					
ALKYLATION			11.3	7.5	18.8
CAT POLYMERIZATION		2.3		5.2	7.5
NAPHTHA HDS		8.5	51.0	51.7	111.2
CATALYTIC REFORMER		8.2	37.3	49.8	95.3
BTX EXTRACTION			5.0	2.7	7.7
C4 ISOMERIZATION					
C5/C6 ISOMERIZATION					
LT GAS OIL H'TREATER		14.6	13.5	51.7	79.8
GAS OIL H'TREATER			12.2		12.2
HYDROCRACKER					
RESID H'TREATER					
H-OIL CRACKING				17.9	17.9
HYDROGEN STM-REF				37.6	37.6
ASPHALT PLANT	21.2				21.2
LUBE PLANT			9.4		9.4
LUBE POLISH			5.6		5.6
SOLVENT EXTRACTION					

TABLE 2-3

PAD DISTRICT 2 CONFIGURATIONS
(MBPCD)
(Page 1 of 2)

COMPANY:	AMOCO	AMOCO	ASHLAND	ASHLAND	ASHLAND	SHELL	SUN
CITY:	MANDAN	WHITING	CANTON	CATLETTSBURG	ST. PAUL PARK	WOOD RIVER	TOLEDO
STATE:	ND	IN	OH	KY	MN	IL	OH
CRUDE DISTILLATION	58.0	350.0	66.0	213.4	67.1	264.0	118.0
VACUUM DISTILLATION		186.8	30.4	82.8	29.4	97.1	20.2
DELAYED COKER		22.6					
COKE DRUM		1.3					
FLUID COKER							
VISBREAKER				2.4			
THERMAL CRACKER				51.7			
FLUID CAT CRACKER	29.3	135.4	30.5	73.3	28.1	114.9	54.5
HVY. OIL CRACKER				48.9			
ALKYLATION	2.8	21.6	6.6	11.3	5.5	20.7	6.6
CAT POLYMERIZATION			0.5	0.9	0.3		
NAPHTHA HDS	14.1	81.8	18.8	67.7	12.2	60.2	25.8
CATALYTIC REFORMER	9.4	70.5	18.8	49.4	12.2	91.2	38.5
BTX EXTRACTION		12.2		5.1		3.6	8.0
C4 ISOMERIZATION				4.7			
C5/C6 ISOMERIZATION	3.8	16.9		11.3	7.5		
LT GAS OIL H'TREATER		39.5	6.6	37.6	14.3	82.2	
GAS OIL H'TREATER		58.3	21.6	37.6	21.6	27.3	
HYDROCRACKER						31.5	26.3
RESID H'TREATER							
H-OIL CRACKING							
HYDROGEN STM-REF				18.8		26.6	45.1
ASPHALT PLANT		37.6	11.3	28.2	13.2	26.8	
LUBE PLANT		6.0		8.1		4.3	
LUBE POLISH		4.0				6.6	
SOLVENT EXTRACTION				9.4			10.3

TABLE 2-3

PAD DISTRICT 2 CONFIGURATIONS

(MBPCD)

(Page 2 of 2)

COMPANY:	SUN	TEXACO	TOTAL IN PADD 2
CITY:	TULSA	EL DORADO	
STATE:	OK	KS	
CRUDE DISTILLATION	85.0	80.0	1301.5
VACUUM DISTILLATION	29.0	24.8	500.5
DELAYED COKER	6.9	11.3	40.8
COKE DRUM	0.3	0.6	2.2
FLUID COKER			
VISBREAKER			2.4
THERMAL CRACKER			51.7
FLUID CAT CRACKER	27.6	33.8	527.4
HVY. OIL CRACKER			48.9
ALKYLATION	7.9	9.4	92.4
CAT POLYMERIZATION			1.7
NAPHTHA HDS	22.6	30.8	334.0
CATALYTIC REFORMER	21.6	23.5	335.1
BTX EXTRACTION	1.9	2.8	33.6
C4 ISOMERIZATION	2.2		6.9
C5/C6 ISOMERIZATION			39.5
LT GAS OIL H'TREATER			180.2
GAS OIL H'TREATER		37.6	204.0
HYDROCRACKER			57.8
RESID H'TREATER			
H-OIL CRACKING			
HYDROGEN STM-REF			90.5
ASPHALT PLANT	4.5		121.6
LUBE PLANT	7.1		25.5
LUBE POLISH	9.9		20.5
SOLVENT EXTRACTION	5.5		25.2

TABLE 2-4

PAD DISTRICT 3 CONFIGURATIONS
(MBPCD)
(Page 1 of 2)

COMPANY: CITY: STATE:	AMOCO TEXAS CITY TX	ARCO HOUSTON TX	DIAM SHAMROCK SUNRAY TX	DIAM SHAMROCK THREE RIVERS TX	SHELL DEER PARK TX	SHELL NORCO LA	SHELL ODESSA TX
CRUDE DISTILLATION	400.0	278.0	85.0	45.0	228.5	218.0	28.6
VACUUM DISTILLATION	179.4	124.2	43.2	18.4	70.8	71.8	9.2
DELAYED COKER	34.8	36.7				19.7	
COKE DRUM	1.9	2.3				0.9	
FLUID COKER							
VISBREAKER							
THERMAL CRACKER					68.6	97.3	
FLUID CAT CRACKER	222.8	73.3	42.3	16.0	65.8	95.9	10.8
HVY. OIL CRACKER							
ALKYLATION	21.6	8.5	8.2	5.6	7.3	12.7	2.8
CAT POLYMERIZATION			4.3			9.4	
NAPHTHA HDS	127.8	107.2	16.9	8.5	96.4	53.6	10.3
CATALYTIC REFORMER	123.1	63.9	15.0	7.5	51.7	28.2	10.3
BTX EXTRACTION	42.3	10.9			18.0		0.3
C4 ISOMERIZATION			1.3				
C5/C6 ISOMERIZATION	20.7						
LT GAS OIL H'TREATER	45.1	84.2			77.6		
GAS OIL H'TREATER	54.5	43.2			42.3	65.8	
HYDROCRACKER	49.8				9.4	26.0	
RESID H'TREATER							
H-OIL CRACKING	56.4						
HYDROGEN STM-REF	169.2				61.1	65.8	
ASPHALT PLANT			3.3		4.6		
LUBE PLANT		6.0		0.9	9.4		
LUBE POLISH		5.6			61.1		
SOLVENT EXTRACTION			10.3	6.6			

TABLE 2-4

PAD DISTRICT 3 CONFIGURATIONS
(MBPCD)
(Page 2 of 2)

COMPANY:	TEXACO	TEXACO	TEXACO	TOTAL IN PADD 3
CITY:	EL PASO	PORT ARTHUR	CONVENT	
STATE:	TX	TX	LA	
CRUDE DISTILLATION	17.0	250.0	225.0	1775.1
VACUUM DISTILLATION		115.9	69.0	701.9
DELAYED COKER	3.8			95.0
COKE DRUM	0.1			5.2
FLUID COKER				
VISBREAKER			11.3	11.3
THERMAL CRACKER				165.9
FLUID CAT CRACKER	8.5	128.3	84.6	748.3
HVY. OIL CRACKER				
ALKYLATION	1.4	8.5	11.7	88.3
CAT POLYMERIZATION	0.5			14.2
NAPHTHA HDS	4.5	37.6	37.6	500.4
CATALYTIC REFORMER	4.5	37.6	37.6	379.4
BTX EXTRACTION				71.5
C4 ISOMERIZATION	0.5			1.8
C5/C6 ISOMERIZATION				20.7
LT GAS OIL H'TREATER		61.1	95.9	363.9
GAS OIL H'TREATER				205.8
HYDROCRACKER		14.1		99.3
RESID H'TREATER				
H-OIL CRACKING			32.9	89.3
HYDROGEN STM-REF				296.1
ASPHALT PLANT		13.2		21.1
LUBE PLANT		14.9		31.2
LUBE POLISH		17.4		84.1
SOLVENT EXTRACTION		11.3		28.2

TABLE 2-5

PAD DISTRICT 4 CONFIGURATIONS
(MBPCD)

COMPANY:	AMOCO	AMOCO	TOTAL IN PADD 4
CITY:	CASPER	SALT LAKE CITY	
STATE:	WY	UT	
CRUDE DISTILLATION	40.0	40.0	80.0
VACUUM DISTILLATION	6.4		6.4
DELAYED COKER			
COKE DRUM			
FLUID COKER			
VISBREAKER			
THERMAL CRACKER			
FLUID CAT CRACKER	15.2	20.7	35.9
HVY. OIL CRACKER			
ALKYLATION	1.6	3.8	5.4
CAT POLYMERIZATION			
NAPHTHA HDS	6.7	5.6	12.3
CATALYTIC REFORMER	5.6	5.6	11.2
BTX EXTRACTION			
C4 ISOMERIZATION			

TABLE 2-6

PAD DISTRICT 5 CONFIGURATIONS
(MBPCD)
(Page 1 of 2)

COMPANY: CITY: STATE:	ARCO CARSON CA	ARCO FERNDALE WA	ARCO KUPARUK AK	ARCO PRUDHOE BAY AK	EDGINGTON LONG BEACH CA	HAWAIIAN IND. EWA BEACH HI	PARAMOUNT PARAMOUNT CA
CRUDE DISTILLATION	211.0	156.0	12.0	22.0	41.6	61.5	46.5
VACUUM DISTILLATION	100.8	86.5			19.5	27.6	25.8
DELAYED COKER	50.8	45.1					
COKE DRUM	2.3	2.2					
FLUID COKER							
VISBREAKER							
THERMAL CRACKER							
FLUID CAT CRACKER	67.7						
HVY. OIL CRACKER							
ALKYLATION	6.8						
CAT POLYMERIZATION	2.3						
NAPHTHA HDS	37.6	30.1				12.2	10.8
CATALYTIC REFORMER	42.3	47.0				12.2	10.8
BTX EXTRACTION							
C4 ISOMERIZATION							
C5/C6 ISOMERIZATION							
LT GAS OIL H'TREATER	37.1	16.0					12.7
GAS OIL H'TREATER							6.6
HYDROCRACKER	20.7	47.0				15.0	
RESID H'TREATER							
H-OIL CRACKING							
HYDROGEN STM-REF	65.8	75.2				16.0	
ASPHALT PLANT					14.6		
LUBE PLANT							
LUBE POLISH							
SOLVENT EXTRACTION							

TABLE 2-6

PAD DISTRICT 5 CONFIGURATIONS
(MBPCD)
(Page 2 of 2)

COMPANY: / CITY: / STATE:	SHELL ANACORTES WA	SHELL MARINEZ CA	SHELL WILMINGTON CA	TEXACO ANACORTES WA	TEXACO BAKERSFIELD CA	TEXACO WILMINGTON CA	TOTAL IN PADD 5
CRUDE DISTILLATION	72.0	113.5	111.0	78.0	38.0	75.0	1038.1
VACUUM DISTILLATION	31.7	75.9	57.0	23.9	20.2	38.6	507.5
DELAYED COKER			48.9	12.2		45.1	202.1
COKE DRUM			2.3	0.7		1.6	9.1
FLUID COKER		20.7					20.7
VISBREAKER							
THERMAL CRACKER							
FLUID CAT CRACKER	45.1	73.3	42.8	36.7		33.8	299.4
HVY. OIL CRACKER							
ALKYLATION	11.4	7.5	8.1	6.2		4.1	44.1
CAT POLYMERIZATION		3.0		1.0			6.3
NAPHTHA HDS	25.4	30.1	36.7	18.8	6.1	16.9	224.7
CATALYTIC REFORMER	18.8	21.6	22.6	18.8	6.1	32.9	233.1
BTX EXTRACTION		3.0					3.0
C4 ISOMERIZATION	2.7		2.5				5.2
C5/C6 ISOMERIZATION							
LT GAS OIL H'TREATER	19.7	29.1	55.5	20.7			190.8
GAS OIL H'TREATER	7.5	47.0			14.1		75.2
HYDROCRACKER		25.4				18.8	126.9
RESID H'TREATER							
H-OIL CRACKING							
HYDROGEN STM-REF		99.6	33.8				290.4
ASPHALT PLANT		10.3					24.9
LUBE PLANT		4.2					4.2
LUBE POLISH		5.9					5.9
SOLVENT EXTRACTION				7.0			7.0

TABLE 2-7

SUMMARY OF PADD CONFIGURATIONS
(MBPCD)

STATE:	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5	TOTAL U.S.
CRUDE DISTILLATION	374.0	1301.5	1775.1	80.0	1038.1	4568.7
VACUUM DISTILLATION	156.4	500.5	701.9	6.4	507.5	1872.7
DELAYED COKER	12.7	40.8	95.0		202.1	350.6
COKE DRUM	2.8	2.2	5.2		9.1	19.3
FLUID COKER	41.4				20.7	62.1
VISBREAKER		2.4	11.3			13.7
THERMAL CRACKER		51.7	165.9			217.6
FLUID CAT CRACKER	179.0	527.4	748.3	35.9	299.4	1790.0
HVY. OIL CRACKER		48.9				48.9
ALKYLATION	18.8	92.4	88.3	5.4	44.1	249.0
CAT POLYMERIZATION	7.5	1.7	14.2		6.3	29.7
NAPHTHA HDS	111.2	334.0	500.4	12.3	224.7	1182.6
CATALYTIC REFORMER	95.3	335.1	379.4	11.2	233.1	1054.1
BTX EXTRACTION	7.7	33.6	71.5		3.0	115.8
C4 ISOMERIZATION		6.9	1.8	2.8	5.2	16.7
C5/C6 ISOMERIZATION		39.5	20.7			60.2
LT GAS OIL H'TREATER	79.8	180.2	363.9		190.8	814.7
GAS OIL H'TREATER	12.2	204.0	205.8		75.2	497.2
HYDROCRACKER		57.8	99.3		126.9	284.0
RESID H'TREATER						
H-OIL CRACKING	17.9		89.3			107.2
HYDROGEN STM-REF	37.6	90.5	296.1		290.4	714.6
ASPHALT PLANT	21.2	121.6	21.1		24.9	188.8
LUBE PLANT	9.4	25.5	31.2	1.4	4.2	71.7
LUBE POLISH	5.6	20.5	84.1		5.9	116.1
SOLVENT EXTRACTION		25.2	28.2		7.0	60.4

SECTION 3

SUMMARY OF SURVEY RESULTS

Each company participating in this survey was initially contacted by telephone. A letter, which included an outline of the information being sought, followed the initial contact. The outline, rather than a questionnaire, was used to help identify topics of interest and the kinds of people who should be involved in the requested interview. This choice was made because most companies had no advance knowledge of Air Force interest in HDJF and, therefore, have no internal study material from which to draw the requested information.

This section contains an explanation of the survey outline and summarizes the information derived.

3.1 PROCESSING ROUTES TO HDJF PRODUCTION

Regardless of the boiling range, achieving a desired minimum volumetric heat of combustion requires a minimum density. This is primarily because most hydrocarbons in the kerosene/heating oil boiling range have roughly the same gravimetric heat of combustion. Increasing density is, therefore, the means of increasing the volumetric heat of combustion.

API shows gravimetric heat of combustion (net) being predicted by a cubic function of API gravity.(1) Multiplying

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(1) API Data Book, pg. 14-11, Equation 14A1.3-4.

this function by the expression for pounds per gallon (in terms of API gravity), namely:

$$\frac{8.33 \times 141.5}{131.5 + G}$$

where G is the API gravity, and assuming a sulfur content of 0.1 wt. percent produces the expression:

$$\frac{19{,}802{,}000 + 64{,}238.9G - 255.777G^2 - 2.23952G^3}{131.5 + G}$$

Setting the above expression equal to 130,000 and solving for G produces the cubic equation:

$$G + 0.0038895G^2 + 0.00003406G^3 - 41.165 = 0$$

The real root of this equation is 34.957, which means that any distillate having an API gravity of 35.0 or lower would provide a volumetric heat of combustion of 130,000 BTU/gallon or better.

Two main sources of high density distillates in modern refineries are from segregated naphthenic crude processing and from thermal cracking of gas oils and residua. Near-term HDJF requires a kerosene boiling-range distillate. Far-term HDJF allows a heating oil boiling-range distillate. Some refineries could produce some volume of either fuel using existing processes and within current operations. Segregated product storage and oil movement facilities would probably be required additions. Survey information was insufficient to characterize where such facilities would not be needed.

3.1.1 Naphthenic Crude Processing

Responses from the companies surveyed indicates that segregation of naphthenic crudes is practical only where there is an established demand for them as low-cold-test lube feedstocks.* In these cases, the kerosene and heating oil distillates offer good quality HDJF feedstock potential. Treatment for storage stability and control of sulfur content could require further downstream processing. Where surplus combustion-property quality exists, blending of cracked distillates would increase density and extend production potential.

Crude distillation operations are flexible enough to provide appropriate boiling range control for either near-term or far-term specifications. The latter may, however, involve competition with demands for the lightest form of lube blendstock. Since lube stocks carry a premium value, far-term fuels made from naphthenic crudes would be relatively expensive. Blending with cracked distillates offers a means for offsetting this high alternate value as well as any processing cost for storage stability or other property control.

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*Estimating potential HDJF from all known naphthenic crude production would be very misleading since costs of segregated gathering, processing and transporting facilities could vary from insignificant to impractical additions to crude cost.

3.1.2 Cracking

Output from cat cracking or hydrocracking offers a potentially large volume of HDJF feedstocks in the form of distillates in the kerosene or heating oil boiling range. Steam cracking of a wide range of feedstocks is employed to produce light olefins to serve as chemicals, plastics, resins and polymer feedstocks. Distillates from visbreaking and coking are typically not separated from the gas oil produced by these processes and are, therefore, normally routed to fluid cat cracking or hydrocracking. Hydrocracking, in particular when fed with cracked distillate or cracked gas oil, can produce distillates with significant naphthenic and aromatic contents. Fluid cat cracking produces a highly aromatic distillate. Both processes are widely used.

The most widely available sources of distillates for HDJF production are cat cracked and hydrocracked distillate. Cat cracked distillate, called light cycle oil (LCO), is either blended into heating oil or fed to hydrocracking. Hydrocracked distillate is typically recycled to extinction. Some hydrocrackers are operated to produce hydrocracked kerosene which is normally blended into conventional jet fuel. When the hydrocracker feedstock is a cracked distillate or gas oil (rather than a virgin gas oil), the distillate product is high in aromatic content, making it less suitable as a conventional jet-fuel blendstock.

Since HDJF is to replace part of the current JP-4 demand, refiners will not have to run additional crude. Instead, they will rearrange stream dispositions and adjust

operating conditions.* Disposing of naphtha stocks currently used in JP-4 and replacement of distillate fuel volumes shifted to HDJF will probably incur some added operating cost.

3.2 SURVEY INFORMATION OUTLINE

An attachment to each letter of request for survey participation briefly described the purpose and plan of the HDJF Availability Study and included a discussion outline. The purpose of the latter was to help participants prepare for the interview, to identify the kinds of information being sought and to guide the selection of personnel who should attend. A copy of this attachment is presented in Appendix A of this report.

Depending on the organizational structure and size of each participating company, one or more persons attended and represented the following areas:

1) Crude Supply,

2) Refining Operations/Coordination,

3) Process Engineering,

4) Product Sales/Marketing,

5) Research and Development, and

6) Refinery Planning.

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*Small adjustments to crude throughput may result from adjusting operations to make HDJF instead of JP-4.

The discussion outline identifies five main topics. These are:

1) Feedstock descriptions, availabilities, and qualities,

2) Processing considerations,

3) Cost implications,

4) Producibility estimates, and

5) Feedstock sample supply.

Applying the adjectives near-term and far-term to HDJF's caused come confusion in early interviews. Implied in these adjectives was the concept that far-term meant 5-10 years into the future. While that may be ultimately required, it was explained that far-term fuels were relaxed in qualities that could require aircraft engine/fuel systems design changes. A clear distinction between abilities to produce near-term or far-term fuels is not possible. It would be possible for some refineries to produce far-term (or near-term) fuels today by simply adjusting operating conditions to produce a wider boiling-range distillate from appropriate crude oils. Whether meeting near-term or far-term specifications, other refineries would require capital investment to produce HDJF.

3.3 NEAR-TERM PRODUCTION

Estimates of production of near-term HDJF from refineries operated by the surveyed companies are presented in Table 3-1. Table 3-1 estimates depend on assumed yields of straight-run kerosene from appropriate crudes, kerosene from residuum hydrocracking, gas oil hydrocracking and, in one case, from treated coker kerosene. In two cases, a portion of straight-run and hydrocracker distillates are assumed available through cut-point adjustment of distillation operations.

TABLE 3-1

NEAR-TERM POTENTIAL FROM SURVEYED REFINERIES

(MBPCD)

COMPANY	CITY	STATE	STRAIGHT RUN KEROSENE	STRAIGHT RUN DISTILLATE	HYDROCRACKER KEROSENE	H'CRK/H-OIL DISTILLATE	TREATED COKER KEROSENE
AMOCO	SAVANNAH	GA					
AMOCO	YORKTOWN	VA					
SUN	MARCUS HOOK	PA	3.0				
TEXACO	DELAWARE CITY	DE				1.8	
TOTAL IN PADD 1			3.0	0.0	0.0	1.8	0.0
AMOCO	MANDAN	ND					
AMOCO	WHITING	IN	2.7				
ASHLAND	CANTON	OH					
ASHLAND	CATLETTSBURG	KY					
ASHLAND	ST. PAUL PARK	MN					
SHELL	WOOD RIVER	IL					
SUN	TOLEDO	OH	3.0			14.2	
SUN	TULSA	OK					
TEXACO	EL DORADO	KS					
TOTAL IN PADD 2			5.7	0.0	0.0	14.2	0.0
AMOCO	TEXAS CITY	TX				36.7	
ARCO	HOUSTON	TX	1.0				
DIAMOND SHAMROCK	SUNRAY	TX					
DIAMOND SHAMROCK	THREE RIVERS	TX	0.4	.45			
SHELL	DEER PARK	TX	20.3				
SHELL	NORCO	LA					
SHELL	ODESSA	TX					
TEXACO	EL PASO	TX					
TEXACO	PORT ARTHUR	TX	1.8		7.6		
TEXACO	CONVENT	LA				3.3	
TOTAL IN PADD 3			23.5	.45	7.6	40.0	0.0
AMOCO	CASPER	WY					
AMOCO	SALT LAKE CITY	UT					
TOTAL IN PADD 4			0.0	0.0	0.0	0.0	0.0
ARCO	CARSON	CA			10.8		5.0
ARCO	FERNDALE	WA					
ARCO	KUPARUK	AK					
ARCO	PRUDHOE BAY	AK					
EDGINGTON	LONG BEACH	CA	3.1				
HAWAIIAN IND.	EWA BEACH	HI	13.3	4.5	7.8		
PARAMOUNT	PARAMOUNT	CA	1.4				
SHELL	ANACORTES	WA					
SHELL	MARINEZ	CA	14.7		7.7		
SHELL	WILMINGTON	CA					
TEXACO	ANACORTES	WA					
TEXACO	BAKERSFIELD	CA					
TEXACO	WILMINGTON	CA			10.2		
TOTAL IN PADD 5			32.5	4.5	36.5	0.0	5.0
TOTAL			64.7	4.95	44.1	56.0	5.0

3.4 FAR-TERM PRODUCTION

In addition to adjusting operations to widen the boiling range of distillates for HDJF production, it is possible that some amount of dearomatization may be required to protect combustion characteristics, e.g., to meet hydrogen content restrictions. Dearomatization requires hydrogenation at high partial-pressures of hydrogen and in the presence of a suitable catalyst. Processing technology is well known but not routinely applied in present-day refining operations.

Constructing hydro-dearomatization capacity could involve new vessels, piping, pumps, exchangers, valves, heaters, etc., or might be derived from revamping of shut-down hydrocracking facilities. Savings in capital required for new capacity has led to recent use of revamping because of the availability of good-condition equipment in shut-down refineries. The amount of saving in capital investment is, however, uncertain because availability of suitable shut-down facilities and revamping/relocation costs are very difficult to estimate. An indication of equipment available is provided by the summary of shut-down facilities presented in Appendix B.

Determining how many shut-down process units are potentially available (and applicable) is beyond the scope of this phase and may be unattainable without significant change of scope in later phases.

Estimates of far-term HDJF production have been prepared assuming adequate capital for installing hydro-desulfurization capacity for all LCO from existing cat cracking capacity. It has been further assumed that existing process capacity would allow for needed shifts in operations to replace some part of JP-4 production with HDJF. Table 3-2 presents estimated production of far-term HDJF.

TABLE 3-2

FAR-TERM POTENTIAL FROM SURVEYED REFINERIES
(MBPCD)
(Page 1 of 2)

COMPANY	CITY	STATE	STRAIGHT RUN KEROSENE	STRAIGHT RUN DISTILLATE	HYDROCRACKER KEROSENE	H'CRK / H-OIL DISTILLATE	FCC LIGHT CYCLE OIL	REFORMER BOTTOMS	PYROLYSIS FUELS	TREATED COKER KEROSENE
AMOCO	SAVANNAH	GA								
AMOCO	YORKTOWN	VA								
SUN	MARCUS HOOK	PA								
TEXACO	DELAWARE CITY	DE								
TOTAL IN PADD 1			0.0	3.5	0.0	5.5	32.2	0.0	0.0	0.0
AMOCO	MANDAN	ND								
AMOCO	WHITING	IN								
ASHLAND	CANTON	OH								
ASHLAND	CATLETTSBURG	KY								
ASHLAND	ST. PAUL PARK	MN								
SHELL	WOOD RIVER	IL								
SUN	TOLEDO	OH								
SUN	TULSA	OK								
TEXACO	EL DORADO	KS								
TOTAL IN PADD 2			2.7	7.4	0.0	14.2	78.1	16.4	0.0	0.0
AMOCO	TEXAS CITY	TX								
ARCO	HOUSTON	TX								
DIAMOND SHAMROCK	SUNRAY	TX								
DIAMOND SHAMROCK	THREE RIVERS	TX								
SHELL	DEER PARK	TX								
SHELL	NORCO	LA								
SHELL	ODESSA	TX								
TEXACO	EL PASO	TX								
TEXACO	PORT ARTHUR	TX								
TEXACO	CONVENT	LA								
TOTAL IN PADD 3			21.7	24.78	7.6	51.8	121.8	28.7	0.94	0.0

TABLE 3-2

FAR-TERM POTENTIAL FROM SURVEYED REFINERIES
(MBPCD)
(Page 2 of 2)

COMPANY	CITY	STATE	STRAIGHT RUN KEROSENE	STRAIGHT RUN DISTILLATE	HYDROCRACKER KEROSENE	H'CRK / H-OIL DISTILLATE	FCC LIGHT CYCLE OIL	REFORMER BOTTOMS	PYROLYSIS FUELS	TREATED COKER KEROSENE
AMOCO	CASPER	WY								
AMOCO	SALT LAKE CITY	UT								
TOTAL IN PADD 4			0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0
ARCO	CARSON	CA								
ARCO	FERNDALE	WA								
ARCO	KUPARUK	AK								
ARCO	PRUDHOE BAY	AK								
EDGINGTON	LONG BEACH	CA								
HAWAIIAN IND.	EWA BEACH	HI								
PARAMOUNT	PARAMOUNT	CA								
SHELL	ANACORTES	WA								
SHELL	MARINEZ	CA								
SHELL	WILMINGTON	CA								
TEXACO	ANACORTES	WA								
TEXACO	BAKERSFIELD	CA								
TEXACO	WILMINGTON	CA								
TOTAL IN PADD 5			32.5	42.4	36.5	27.7	53.9	0.0	0.0	5.0
TOTAL			56.9	78.08	44.1	99.2	292.4	45.1	0.94	5.0

3.5 HDJF FEEDSTOCK SAMPLES

More than 70 different feedstocks have been offered by the companies participating in the survey. These range from straight-run kerosenes to a variety of cracked distillates, including a kerosene from Canadian Tar Sands crude processing. Samples represent geographic sources from all major refining centers. Only one feedstock was, however, offered from the Rocky Mountain region.

Table 3-3 lists each feedstock, the State of origin, and certain pertinent remarks. From these, a set of 12 samples must be selected for Phase II of his study.

TABLE 3-3

FEEDSTOCKS OFFERED FOR PHASE II
(Page 1 of 3)

No.	Feedstock	State	Samples	Remarks
1	SR Kerosene and Distillate from Naphthenic Crude (Lube Operation)	TX	2	Picket Ridge/Manvel Crudes
2	SR Kerosene and Distillate from Naphthenic Crude (Lube Operation)	TX	2	Gulf Coast A Crude
3	HCK Kerosene and Distillate from			
	a. Lt. Cycle Oil Feed	TX	2	
	b. Coker Gas Oil Feed	DE	1	Maybe no distillate
	c. Resid Feed	LA	2	
	d. Coker Gas Oil & SR Distillate	KS	2	
4	HCK Bottoms (No. 2 Distillate)	CA	1	
5	SR Fractions from Naphthenic Crude (Lube Operations)	TX		Mirando Crude
	a. Kerosene		5	Requested
	b. 45 Vis Lube Cut		5	Requested
	c. 45 Vis Lube Cut, HTR		5	Requested
	d. 60 Vis Lube Cut		5	Requested
	e. 60 Vis Lube Cut, HTR		5	Requested
6	FCC Light Cycle Oil from Vacuum Gas Oil	TX	1	
7	SR Kerosene and Distillate from Naphthenic Crudes (Lube Operation)	TX	2	Refugio Light/Heavy Coastal Crudes
8	Pyrolysis Fuel Oil from Ethylene Plant	TX	1	
9	Hydrotreated Kerosene from Coker Distillate (high severity aromatics saturation)	CA	1	
10	FCC Light Cycle Oil from Vacuum and Coker Gas Oils	CA	6	After gas oil hydrotreater start-up
11	HCK Kerosene and Distillate (Recycle) from Vacuum and Coker Gas Oils	WA	2	ANS Crude

TABLE 3-3

FEEDSTOCKS OFFERED FOR PHASE II
(Page 2 of 3)

No.	Feedstock	State	Samples	Remarks
12	SR Fractions from High Naphthelene Crude (Not Lube Operation)	CA		Wilmington Crude
	a. Kerosene		2	Requested
	b. Diesel		2	Requested
13	SR Kerosene and Distillate from Naphthenic Crude (Lube Operation)	PA	2	Grade A Crude
14	FCC Light Cycle Oil	PA	1	
15	Aromatic Chemicals Operations	OH		
	a. Xylene Tower Bottoms		2	
	b. Hydeal Bottoms		2	
16	HCK Distillate (Recycle) from SR Distillate and LCO Feedstocks	OH	2	
17	Kerosene from Canadian Tar Sands Crude (previously through coking and hydrotreating)	OH	1	
18	Light Aromatic Extract from Furfural Treating of Lube Cuts	OK	1	
19	FCC Light Cycle Oil	OK	1	
20	SR Kerosene and Distillate from Naphthenic Crudes	CA		
	a. San Joaquin Valley Heavy		2	
	b. San Joaquin Valley Lube		2	
	c. Elk Hills Shallow		2	
	d. Kern Ridge Diatomite		2	
21	HCK Kerosene (35% Aromatics) from Catalytic Gas Oil Feed	CA	1	
22	FCC Light Cycle Oil from Vacuum and Coker Gas Oils	CA	1	Naphthenic Crude
23	SR Kerosene and Distillate from Naphthenic Crude (Lube Operation)	TX	2	Yates Crude
24	Pyrolysis Gas Oil from Ethylene Plant	TX	1	

TABLE 3-3

FEEDSTOCKS OFFERED FOR PHASE II
(Page 3 of 3)

No.	Feedstock	State	Samples	Remarks
25	Pyrolysis Gas Oil from Ethylene Plant	LA	1	
26	SR Kerosene and Distillate from Naphthenic Crude (Not Lube Operation)	CA	2	Line 63 Crude Mix (San Joaquin Valley)
27	Hydrotreated Light Coker Gas Oil produced from Vacuum Bottoms of Kern Heavy Crude	CA	1	Coker currently not operating
28	FCC Light Cycle Oil from Resid Feed	KY	1	100% Aromatics, Requested
29	FCC Light Cycle Oil from Gas Oil Feed	IN,TX	2	60% Aromatics, 20% Naphthenes
30	Catalytic Reformer Bottoms	IN,TX	2	380-460°F, 95% Aromatics
31	Pyrolysis distillate from Olefins Plant	TX	1	20-40% Aromatics
32	FCC Decant Oil	IN,TX	2	95% Aromatics, Multi-Ring
33	HCK Recycle from Distillate Feed	TX	1	20-40% Aromatics
34	HCK Light Distillate from Resid Feed	TX	1	22% Aromatics, 38% Naphthenes
35	HCK Heavy Distillate from Resid Feed	TX	1	27% Aromatics, 38% Naphthenes
36	SR Distillates from Naphthenic Crudes (TX, LA, WY, Trinidad)		4	Not currently segregated
37	SR Kerosene and Distillate from Naphthenic Crude (Not Lube Operation)	HI	2	Ardjuna Crude (Indonesia)
38	HCK Kerosene and Recycle from Vacuum Gas Oil Feed (650-950°F)	HI	2	Various Imported Crudes

SECTION 4

PRODUCTION OF HIGH-DENSITY JET FUEL: VOLUMES AND COSTS

This section presents the results of projections of production capabilities for HDJF in each of the five PAD Districts. Also, summarized are cost estimates for these projected volumes. Volume and cost estimates depend on simplifying assumptions and extrapolation of survey results and must be recognized as "first approximations." Improved estimates are the objectives of later activities of this project.

Cost estimates have been prepared using generic process economic considerations. None of the interviewed companies provided cost estimates, nor were they expected to. Cost information is not made public, because it is considered confidential and is not shared to avoid any implication of anti-trust action.

4.1 NEAR-TERM FUEL ESTIMATES

Projected near-term HDJF production capability of U.S. refiners is summarized in Table 4-1. As indicated by these projections, regional capability varies significantly. The U.S. total is, however, more than adequate to replace all current JP-4 production of approximately 200,000 barrels per day. As mentioned earlier in this section, these projections must be viewed as "first approximations." Further, they are probably representative of maximum volumes for current refining capability. Projection has embodied the underlying premise that no process capacity addition or expansion is involved.

TABLE 4-1

TOTAL U.S. POTENTIAL NEAR-TERM HDJF PRODUCTION
(MBPCD)

	STRAIGHT RUN KEROSENE	STRAIGHT RUN DISTILLATE	HYDROCRACKER KEROSENE	HYDROCRACKER DISTILLATE	H-OIL LIGHT DISTILLATE	TREATED COKER KEROSENE	TOTAL
TOTAL IN PADD 1	6.0	0.0	0.0	0.0	1.8	0.0	7.8
TOTAL IN PADD 2	11.4	0.0	0.0	14.2	0.0	0.0	25.6
TOTAL IN PADD 3	47.0	0.9	21.9	24.9	15.1	0.0	109.8
TOTAL IN PADD 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL IN PADD 5	65.0	9.0	101.9	0.0	0.0	5.0	180.9
TOTAL U.S.	129.4	9.9	123.8	39.1	16.9	5.0	324.1

Straight-run kerosene and distillate projections are based on an assumption that segregated production and processing of naphthenic crudes can be doubled without major expenditure for field facilities. This is, in our opinion, an optimistic view. J&A Associates estimate of 1,005,200 barrels per day of naphthenic crude production[2)] indicates that the naphthenic crude accounting for the production identified in the survey is 35 percent of domestic production. Doubling segregated production would therefore account for 70 percent of J&A's national production estimate.

Hydrocracked kerosene and distillate estimates are the survey sample estimates expanded by the ratio of process capacity in each region to that comprised in the refineries of the surveyed companies in each region. Treated coker kerosene was not scaled upward because it appears to be a unique type of operation.

4.2 FAR-TERM FUEL ESTIMATES

Projected far-term HDJF production capability of U.S. refiners is summarized in Table 4-2. Extending boiling range and allowing for capital investment in hydro-dearomatization capacity increases HDJF potential from 324,000 to 1,437,000 barrels per calendar day. This latter figure is seven-fold greater than current JP-4 supply, which indicates far-term supply potential, even at modest cost increases over JP-4, is very likely more than adequate for current Air Force needs.

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2) "High Density Jet Fuel Supply and Specifications, J&A Associates, January 1986, Subcontract G-9046(8827)-544 of Contract No. F33615-84-C-2410.

TABLE 4-2

TOTAL U.S. POTENTIAL FAR-TERM HDJF PRODUCTION
(MBPCD)

	STRAIGHT RUN KEROSENE	STRAIGHT RUN DISTILLATE	HYDROCRACKER KEROSENE	H'CRK / H-OIL DISTILLATE	FCC LIGHT CYCLE OIL	REFORMER BOTTOMS	TREATED COKER KEROSENE	TOTAL
TOTAL IN PADD 1	0.0	7.0	0.0	5.5	107.0	0.0	0.0	119.5
TOTAL IN PADD 2	5.4	14.8	0.0	14.2	196.1	16.7	0.0	247.2
TOTAL IN PADD 3	43.4	50.0	21.9	51.8	395.3	55.9	0.0	618.3
TOTAL IN PADD 4	0.0	0.0	0.0	0.0	37.2	0.0	0.0	37.2
TOTAL IN PADD 5	65.0	84.8	101.9	27.7	130.8	0.0	5.0	415.2
TOTAL U.S.	113.8	156.6	123.8	99.2	866.4	72.6	5.0	1437.4

Projection of straight-run kerosene and distillate depend on the same assumption of doubling current segregation of naphthenic crude production. Kerosene from hydrocracking is scaled by the ratio of capacity of refineries in sampled companies to total regional capacity. The same procedure applies to H-Oil distillate and cat cracked light cycle oil. No scaling was applied to hydrocracked distillate, because this would imply changes in feedstock to hydrocracking and modification of hydrocracker fractionators. Reformer bottoms (C_9 and heavier aromatics) volumes were scaled by the ratio of reported extraction capacities for the region and the sampled refineries.

Process capacity totals for each PAD District and for the nation are presented in Table 4-3. Capacities for sampled refineries are summarized and presented in Section 2 (Tables 2-2 through 2-7). Comparison of these figures shows that the survey covered a representative set of refineries.

TABLE 4-3

TOTAL U.S. REFINING CAPACITY
(MBPCD)

PROCESS UNIT	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5	TOTAL
CRUDE DISTILLATION	1412.2	3306.8	6911.4	560.6	2948.8	15139.8
VACUUM DISTILLATION	679.6	1204.1	2762.9	187.1	1427.3	6261.0
DELAYED COKER	32.9	261.7	502.7	11.9	353.9	1163.1
COKE DRUM	3.7	13.5	26.2	1.4	19.3	64.1
FLUID COKER	50.8		7.5	15.5	81.3	155.1
VISBREAKER	12.2	5.0	64.4		51.6	133.2
THERMAL CRACKER		52.6	177.8	2.3	18.9	251.6
FLUID CAT CRACKER	594.9	1324.2	2428.7	208.8	726.6	5283.2
HVY OIL CRACKER		48.9	107.1			156.0
ALKYLATION	60.3	224.5	423.9	27.7	121.9	858.3
CAT POLYMERIZATION	9.2	18.8	35.4	11.2	6.4	81.0
NAPHTHA HDS	410.7	849.3	1708.7	115.0	606.7	3690.4
CATALYTIC REFORMER	360.9	823.5	1552.2	111.8	602.6	3451.0
BTX EXTRACTION	12.1	34.2	139.2		1.4	186.9
C4 ISOMERIZATION	0.0	14.0	26.4	9.8	15.5	65.7
C5/C6 ISOMERIZATION	23.5	47.5	66.0			137.0
LT GAS OIL H'TREATER	341.1	415.9	1504.5	112.7	415.6	2789.8
GAS OIL H'TREATER	197.4	282.8	547.9	9.4	304.5	1342.0
HYDROCRACKER	51.7	146.3	285.5	9.3	354.4	847.2
RESID H'TREATER			317.7		22.6	340.3
H-OIL CRACKER	17.9		89.3	0.0	35.2	142.4
HYDROGEN STM-REF	94.6	148.5	745.6	25.6	863.7	1878.0
ASPHALT PLANT	133.3	219.0	134.5	27.8	106.5	621.1
LUBE PLANT	33.2	31.7	127.7	1.7	23.8	218.1
LUBE POLISH	12.9	20.5	116.1		6.6	156.1
SOLVENT EXTRACTION	15.0	39.0	149.6	8.5	54.0	266.1

4.3 ESTIMATED COST OF HDJF

In the absence of cost information from survey interviews, production costs for near-term and far-term HDJF have been prepared from generic process economic considerations. The basis for these cost estimates is the concept of replacement of finished products from which HDJF feedstocks would be taken. For near-term fuels, commercial jet fuel pools would be the source feedstocks (blendstocks). Far-term feedstocks would come from heating oil (No. 2 Fuel Oil) pools.

Replacement costs for commercial jet fuel and heating oil were derived from regional refinery model results[3] prepared for internal study purposes. Since these results were based on 1984 backcasting, crude costs were high compared to present-day costs and probable future costs. Replacement cost derives mainly from raw material costs and is, therefore, nearly proportional to crude costs. In the case of commercial jet fuel, replacement cost is shown to be an average of 1.052 times crude cost. Heating oil replacement cost is 1.046 times crude cost. Although these ratios would be expected to vary somewhat as product mix changes, refinery output is currently a similar mix to that of 1984.

Installation of a segregated product storage and loading system may be required at most refineries.* The cost of such facilities cannot be estimated exactly without site-specific detail. Using $20 per barrel for tankage, lines, etc., and 20 days storage, an investment of $400 per daily barrel of product is estimated. Capital recovery and related costs represent a per-barrel cost of $0.274.

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3) Internal regional model development and testing - Bonner & Moore Management Science, 1986.

*Assumes that JP-4 not totally replaced by HDJF.

For far-term production, approximately 50 percent of the product could be hydro-dearomatized light cycle oil. This composition, the other blendstocks being straight-run distillate or hydrocracked products, is estimated to meet a maximum aromatics content of 40 percent. Sulfur content, although not mentioned as a limiting property, would be at prevailing heating oil sulfur contents and probably does not require further reduction. The main cost components added by hydro-dearomatization are capital recovery and hydrogen supply. Using a cost of $1.00 per thousand standard cubic feet (SCF) for hydrogen and consumption of 3,000 SCF per barrel of dearomatizer product and a capital cost of $6.00 per barrel of capacity, processing costs for far-term HDJF total $4.50 per barrel (i.e., half of $3.00 plus $6.00).

These costs as well as blendstock costs are shown in Table 4-4 for both near-term and far-term HDJF at two estimates of crude cost, namely, $15 and $20 per barrel.

TABLE 4-4

COST ESTIMATES FOR HDJF
($/BBL)

	Near-Term		Far-Term	
Crude Cost/Bbl:	$15	$20	$15	$20
Blendstock Replacement	15.78	21.04	15.69	20.92
Hydro-Dearomatization Cost	-	-	4.50	4.50
Product Storage Facilities	0.27	0.27	0.27	0.27
HDJF Cost, $/Bbl:	16.05	21.31	20.46	25.69
HDJF Cost, ¢/Gal:	38	51	49	61

SECTION 5

PROBLEMS DERIVED FROM THE SURVEY

In the course of discussions with personnel of surveyed refining companies, four subjects requiring Air Force attention were encountered. These subjects relate to all potential suppliers of HDJF. Consideration of these subjects will influence how the modeling work of this project will be conducted. Each is discussed in the following paragraphs along with recommendations for dealing with each in subsequent study activities. The subjects are, in our opinion, discussed in descending order of importance.

5.1 PROPERTY RESTRICTIONS AND TRADE-OFFS

In simplistic terms, there is a trade-off among the attainable volumetric heat of combustion, fuel combustion characteristics and cost/volume of HDJF. If, for example, hydrogen content were difficult to meet, (while supplying fuel with a required minimum heating value), the cost and/or volume could be improved by some relaxation of hydrogen content.

In order that refining models properly reflect real quality restrictions and permit exploring the significance of "soft" limits, or targets, it will be necessary for the Air Force to specify upper and/or lower limits on those properties that are required by engine/fuel system performance requirements. Further, where target or desirable properties are specified, an acceptable range must also be defined. Finally, where properties are highly correlated, such as aromatic content and hydrogen content, one must be identified as the primary property. The other will then become dependent, i.e., not a controlling property.

Table 5-1 summarizes the properties that will be recognized in refining models to be used in Phases II and III. Certain properties will be reported but not used as limitations. For example, distillation properties such as percent distilled at 400° and 550° will be reported but will not be imposed as quality constraints. Freeze point will not be imposed as a quality constraint.* Instead, pour point will be reported but not imposed as a constraint. Pour point data are available in the data library available for this study. Pour point blending data, however, are not accurate and are used with caution since control of low-temperature properties is primarily by selection of appropriate segregated crudes, use of pour point depressants and cut-point control. The latter control cannot be modeled accurately because little is known about the effect of cut-point (in general) on other properties.

Available data for aromatic content satisfy the need to characterize this property. Other hydrocarbon types, namely, paraffin and naphthene content, are not supported by the data library and are not routinely reported in the literature. If adequate data are not found, these properties cannot be modeled. If they are obtained, they will be reported. Sulfur content, although not specified in the Contract Statement of Work, is assumed to be that imposed by current JP-4 and JP-5 specifications.

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*Meeting minimum heating value limits will require such high concentration of ring-structure hydrocarbons that freeze point is probably not a problem.

TABLE 5-1

PROPERTIES RECOGNIZED IN REFINING MODELS

PROPERTY	LIMITATION NEAR-TERM	LIMITATION FAR-TERM
Specific Gravity	0.85 (min.)	0.86 (min.)
Flash Point, °C	60 (min.)	60 (min.)
Pour Point*, °C	reported	reported
Viscosity @-20°C, cSt	12 (max.)	24 (max.)
Boiling Range	(Controlled by selection from appropriate blendstocks.)	
Heat of Combustion, MBtu/Gal.	130 (min.)	135† (min.)
Aromatic Content, Vol. Pct.	25 (max.)	40 (max.)
Sulfur Content, Wt. Pct.	0.40 (max.)	0.40 (max.)
Paraffins and Naphthene Content, Vol.Pct.	(Lack data to include.)	
Hydrogen Content, Wt. Pct.	(Not modeled - Derived by correlation with other properties.)	
Smoke Point, mm	15 min. or reported	13 min. reported

*Pour point data will be used to indicate low-temperature characteristics rather than freeze point since the former are in the data library which will be used in modeling.

†May be impossible without relaxation of maximum aromatics content.

Hydrogen-content data are not routinely reported and are not part of the data library to be used in this project. Although the API data book has a correlation* that relates carbon-to-hydrogen ratio to other properties (i.e., API gravity, mean average boiling point, K factor and analine point), accuracy of the correlation is unknown and does not compare favorably to a few observations from jet-fuel-related research It is our recommendation, therefore, that maximum aromatic content and minimum smoke point be used as model constraints.

To examine the trade-off between combustion properties and heat-of-combustion (as well as trade-off of these properties with cost and/or volume of production) we suggest that sensitivity cases be run to examine each such trade-off. Determining which trade-off to study and to what length will be best determined from results of models for Tasks II and III.

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*API Data Book, pp. 2-11.

5.2 COST OF CAPITAL

A prevalent concern of many of the companies surveyed is the problem of allocating investment capital to projects which depend on an annual competitive-bid award. As stated by several, "Military jet fuel must be viewed as a one-year business." Obviously, a payout period of one year would impose such a high capital recovery burden that manufacturing cost of HDJF could be unreasonably high. Volumes of HDJF produced without the need for capital investment, particularly without process investment, would be much less costly than the next increment, if payout must be achieved in a single year. Modeling typical investment decision making would involve a cost of capital much greater than that normally employed. Using a realistic cost of capital would not reflect the refining industry's true ability to invest in HDJF processing unless the activity were supported by some kind of subsidy, loan guarantee, or procurement assurance.

It is recommended that cost of capital be set at 15 percent and an economic and depreciation life of 13 be used to define capital recovery. This is representative of acceptable return on equity and indicative of the capital burden for long-term financial health. It does not represent "hurdle rates" used for corporate investment decision making. It will, however, provide model results that reflect a sensible balance between raw material, operating and capital costs. The effect of requiring a one-year payout can be calculated as a post-solution analysis.

5.3 JP-4 SUBSTITUTION

Another persistent topic of discussion during survey interviews is the matter of how much JP-4 would be replaced by HDJF. An estimate of 25 percent was mentioned in early conversations with Air Force personnel. In the absence of any other number, official or otherwise, this estimate was used in these discussions. Recently, JP-4 has been approximately 1.5 percent of total refinery output. Nationally, this amounts to approximately 206,000 barrels per day. If HDJF replaces 25 percent of this volume, output would be approximately 51,500 barrels per day. When this volume is distributed throughout the nation, local demands become relatively small. This might be good in terms of potential supply or bad in terms of being "too small to be of interest."

In the absence of any definitive estimate of the part of JP-4 production which might be replaced with HDJF, it is recommended that refining models be equipped with a constraint on the sum of JP-4 and HDJF productions. By fixing the output of either form of military jet fuel, the model will then be forced to supply the balance as the other fuel. Initial cases exploring HDJF producibility can, thus, be defined at any level of JP-4 replacement adopted for the analysis and can be revised to provide a cost-volume curve for HDJF production.

5.4 REGIONAL SUPPLY REQUIREMENTS

Bearing on the matter of HDJF substitution for JP-4, is how demand for HDJF may be distributed geographically. National security would suggest that many rather than few sources of supply are needed. Cost of supply, on the other hand, may indicate that a few select sources are best. Considering the relatively small volumes that may be required, high local supply cost or limited sources of supply may be the only reasonable alternatives in this situation.

With recommended model structure for constraining the sum of JP-4 and HDJF production (see paragraph 5.3), each regional model can be controlled to output any regionally required volume of HDJF. Defining regional demands will be the responsibility of the Air Force Project Officer (AFWAL/POSF).

APPENDIX A

SURVEY INFORMATION
HIGH-DENSITY JET FUEL STUDY
FOR
WRIGHT-PATTERSON AFB, OH

(Contract No. F33615-85-C-2529)

STUDY PURPOSE AND PLAN

Because they offer an increase in operating range of certain volume-limited aircraft, the Air Force is investigating the potential supply of high-density jet fuels (HDJF). Near term, such fuels would be expected to serve aircraft presently using JP-4 and JP-5 without any modification to engines or fuel systems. Far term, engine and fuel system design modifications may allow an increase in boiling range and aromatics content to attain further increases in density. Target specifications for both near-term and far-term HDJF are shown in Table 1.

The purpose of increasing density is to increase the volumetric energy content of jet fuels. High concentrations of cyclic hydrocarbons are needed to achieve high density. Ring structures should be predominantly naphthenes. Single and especially condensed-ring aromatics must be limited to protect combustion characteristics. Current kerosene-type jet fuels with high naphthene contents approach desired HDJF fuel properties. Higher end-point distillates from naphthenic crudes could approach (or satisfy) far-term properties. High aromatic-content cracked distillates could be modified via hydrogenation to produce high naphthene-content fuels with adequate combustion properties.

TABLE A-1

HIGH-DENSITY JET FUEL PROPERTIES
(Target Specifications)

	Near-Term	Far-Term
Specific Gravity	0.85 (min)	0.86 - 0.90
Flash Point, °F (°C)	140 (60)	140 (60)
Boiling Range, °F (°C)	300-550 (150-290)	300-660 (150-350)
Freezing Point, °F (°C)	-53 (-47)	-53 (-47)
Net Heat of Combustion, BTU/GAL	130,000	140,000
Aromatics, vol. pct.	10-25	10-40

Production of these fuels will be studied by surveying potential supplies, by laboratory analysis and processing of selected fuel components and feedstocks and by modeling specific refineries and regional refinery composites. Information from the survey will guide extrapolation of availability estimates to industry-wide projections. It will also influence laboratory work intended to supply small-volume samples of candidate fuels. Refining models will include projections of availability of appropriate crudes (e.g., naphthenic crudes), processing alternatives and stream property estimates derived from survey input and from the open literature*.

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*Proprietary and confidential information which may be discussed during interviews will be protected and not published unless expressly agreed to by the company being surveyed.

Industry production capability and costs will be determined from model results using Bonner & Moore generic processing and cost data and based on forecasts of refined product demands prepared by Bonner & Moore.

Laboratory work will be performed by Southwest Research Institute at their San Antonio facility. This work will include extensive property analyses of feedstock materials, processing of these materials in pilot plant equipment (as deemed necessary to parallel actual refinery processing needs) and blending and testing of candidate fuels for submission to the Air Force. Volumes required by the Air Force are approximately five liters each of several candidate fuels. Engine, combustor, or aircraft testing is, obviously, not contemplated for these samples.

INFORMATION BEING SOUGHT

Survey discussions will be guided by our needs to fully understand the refining situation(s) surrounding HDJF production. This insight will affect both the laboratory processing program and our modeling efforts. As a guide to selecting appropriate people from your staff, the following outline of discussion topics has been prepared. Other topics that you feel should be discussed may be added to the agenda.

DISCUSSION OUTLINE
CONCERNING
HIGH-DENSITY JET FUEL PRODUCTION

1. Feedstocks (and blend stocks) descriptions, available volumes, qualities:

   1.1 Conventional stocks, currently and potentially available;

      1.1.1 Distillates from suitable crude oils,

      1.1.2 Distillates from downstream processes.

   1.2 Unconventional stocks, currently and potentially available;

      1.2.1 Distillates from petrochemical processes,

      1.2.2 Distillates from synthetic crudes, tar sands oil, and heavy crudes.

      1.2.3 Other

   1.3 Feedstock samples for processing.

2. Processing Considerations:

   2.1 Production/disposition of currently available feedstocks and blend stocks;

   2.2 Production/disposition of potentially available feedstocks and blend stocks;

2.3 Segregation facilities for blend stocks and finished products (assume new jet fuel replaces some part of current JP-4, JP-5, or JP-8 demands).

2.4 Processing Requirements:

2.4.1 Installed, e.g., Merox treating, hydrotreating, rerunning;

2.4.2 Potentially required near- and far-term, e.g., solvent extraction, hydrogenation (aromatics saturation), rerunning, blending;

2.4.3 Product quality considerations; process related, feedstock related, component blending.

3. Cost Implications, near- and far-term:

3.1 New facility costs -- tankage, lines and pumps, processes;

3.2 Curtailing current military jet fuels production;

3.3 Other.

4. Company Estimates of Producibility:

4.1 Near-term cost/volume estimates;

4.2 Far-term cost/volume estimates.

5. Arrangement for Feedstock Samples at SwRI.

APPENDIX B

ESTIMATED INVENTORY OF SHUT-DOWN PROCESS EQUIPMENT

Table B-1, presented below, shows shut-down equipment by PADD and by process type. This equipment is our estimated inventory of shut-down capacity. Total U.S. inventory is shown in the right column of figures.

TABLE B-1

SUMMARY OF REFINING FACILITIES CURRENTLY SHUT DOWN
(MBPCD)

PROCESS UNIT	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5	TOTAL
CRUDE DISTILLATION	248.8	1106.4	1237.4	76.6	285.9	2955.1
VACUUM DISTILLATION	66.3	351.8	203.3	26.7	81.0	729.1
DELAYED COKER		60.9		4.2	12.0	77.1
COKE DRUM		1.8				1.8
FLUID COKER					6.6	6.6
VISBREAKER			11.7			11.7
THERMAL CRACKER		11.0	4.0	4.0	16.0	35.0
FLUID CAT CRACKER	51.6	458.0	208.8	14.0	24.3	756.7
ALKYLATION	1.9	68.2	9.7	0.8	4.2	84.8
CAT POLYMERIZATION		9.7	8.5	0.1	0.2	18.5
NAPHTHA HDS	39.9	237.9	117.5	12.4	25.6	433.3
CATALYTIC REFORMER	23.5	214.2	113.2	11.0	33.0	394.9
BTX EXTRACTION	2.8		8.4			11.2
C4 ISOMERIZATION		0.5				0.5
C5/C6 ISOMERIZATION	3.8	6.1				9.9
LT GAS OIL H'TREATER		130.1	33.8			163.9
GAS OIL H'TREATER	18.8	5.2	75.2	4.0	13.0	116.2
HYDROCRACKER			23.6	6.0	14.2	43.8
RESID H'TREATER			59.2			59.2
H-OIL CRACKING				2.0	7.5	9.5
HYDROGEN STM-REF			24.0	8.0	5.9	37.9
ASPHALT PLANT	20.5	54.5	19.4	5.7	2.4	102.5
LUBE PLANT	2.9	9.8			1.3	14.0

☆U.S.Government Printing Office: 1987 — 748-061/60738